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# R Parity Violating Decays of the Gluino

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## Abstract

Assuming the lightest supersymmetric particle is the gluino, we treat the decays  $\tilde{g} \rightarrow q\bar{q}\nu$  and  $\tilde{g} \rightarrow g\nu$ . Such couplings can be induced by the R parity violating quark-squark-lepton interaction which can also be responsible for neutrino masses and mixings. These R parity violating gluino decays have the same final state structure (jets plus missing energy) as previously considered decays into quark-antiquark-photino and gluon-gravitino but with significantly different gluino lifetimes.

## 1 Introduction

The possibility of the lightest supersymmetric particle (LSP) decaying through R parity violation has been discussed since the early days of supersymmetry [1], many studies have been made (e.g. [2]), and many experimental searches have been undertaken (e.g. [3]). There seem, however, to have been no investigations up to now of the possibility considered here of R parity violating decays of the gluino. Although these would be most relevant if the recent theme of a light or relatively light gluino were to be experimentally confirmed

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they could also be important in the case of a heavy gluino LSP. In some cases [4, 5] the phenomenological advantages of a light gluino have as much to do with a large hierarchy between gluino and squark masses as with a light gluino mass per se. Most recent light gluino investigations have concentrated on the mass region around 12 GeV possibly accompanied by a b squark near 4 GeV [6] , [7]. Alternative possibilities have also been noted [8]. In the minimal supersymmetric standard model (MSSM), a light gluino is typically accompanied by an even lighter photino allowing the decay  $\tilde{g} \rightarrow q\bar{q}\tilde{\gamma}$ . In gauge mediated SUSY breaking models, there is often an ultra-light gravitino below the gluino in mass leading to the decay  $\tilde{g} \rightarrow g\tilde{G}$ . In some models these channels are closed leading to an absolutely stable gluino or to one decaying through R parity violating processes. In this article we assume the gluino is the lightest supersymmetric particle and we consider lepton number violating gluino decays. In section II we treat the decays  $\tilde{g} \rightarrow q\bar{q}\nu$ . The fact that the third generation seems, in some respects, special compared to the first two suggests models in which the R parity violation is tied to the third generation.

If the R parity violation is entirely in the third generation and the gluino lies below the  $b\bar{b}$  threshold, there will be the loop induced decay  $\tilde{g} \rightarrow g\nu$ . This is treated in section III neglecting the possibility of a right-handed neutrino.

Finally, in the presence of a light right-handed neutrino, there is the possibility, treated in section IV, that the dominant decay could be a two loop process coupling the gluino to gluon plus  $\nu_R$ . It might be expected that such a dominant decay mechanism would lead to an ultra-long-lived gluino.

## 2 The gluino decay to quark-antiquark-neutrino

We assume an  $R$  parity violating and lepton number violating term in the superpotential of the form

$$W = \lambda'_{ijk} L_i Q_j D_k \quad (2.1)$$

where  $i, j, k$  are family indices. Then, if the gluino is above a quark-antiquark threshold one will have the gluino decay to  $q\bar{q}\nu$  corresponding to the graph of fig. 1.

The fact that the third generation seems, in some respects, special compared to the first two suggests models in which the R parity violation involves third generation quarks and squarks only. We, therefore, take as a working assumption that the non-zero quark flavor indices in 2.1 are third generation only. In any case, the experimental limits on R parity violating couplings are much less restrictive [2, 9] in the third generation so these could well be dominant. A  $\lambda'$  involving only third generation quarks could be as great as 0.1. Then the gluino decay would be into  $b\bar{b}\nu$  assuming the gluino mass is above the  $2b$  threshold. In this case a light gluino pair production could explain the excess b production seen at Fermilab without requiring the light b squarks of [6].

The signature of such a decay, hadrons plus missing energy, would be identical to the

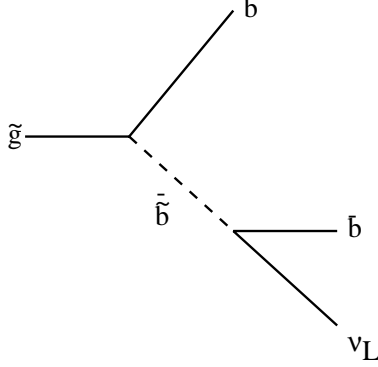


Figure 1: Gluino decay into quark-antiquark neutrino

conventional  $q\bar{q}\tilde{\gamma}$  decay. The inverse width for this latter decay is

$$\tau(\tilde{g} \rightarrow q\bar{q}\tilde{\gamma}) \approx \tilde{m}^4 / (m_g^5 \alpha_s \alpha) \quad (2.2)$$

With a light gluino and a squark mass in the  $100 GeV$  range, this typically results in a gluino lifetime in the nanosecond range which is counter-indicated by the *KTEV* search [10]. If, however, the gluino is the LSP and decays through the R parity violating graph of fig. 1, the lifetime could easily be much longer so that the lightest supersymmetric hadron, presumably the gluino-gluon bound state, would not decay in the sensitive region of a *KTEV* type experiment. \*

$$\tau(\tilde{g} \rightarrow q\bar{q}\nu) \approx \tilde{m}^4 / (m_g^5 \alpha_s \lambda'^2) \quad (2.3)$$

The neutrino mass matrix corresponding to the R parity violation of 2.1 is [12]

$$M_{ii'}^\nu \approx \frac{3}{8\pi^2} \sum_{jk} \lambda'_{ijk} \lambda'_{ikj} m_d(j) m_d(k) / \tilde{m} \quad (2.4)$$

where  $\tilde{m}$  is the assumed degenerate squark mass and  $m_d(k)$  is the down-type quark mass in the  $k$ 'th family. We have also made the simplification of neglecting the CKM quark mixing angles and have assumed that  $A_d - \mu \tan \beta$  is of order  $\tilde{m}$ . If the dominant  $k, j$  are third generation, [12] notes that a  $4.5 eV$   $\nu_e$  mass would correspond to

$$\lambda'_{133} \approx 7 \cdot 10^{-4} \left( \frac{\tilde{m}}{100 GeV} \right)^{1/2} \quad (2.5)$$

although the present indications of a sub-eV neutrino mass would lead to a  $\lambda'$  an order of magnitude below 2.5. Such a relation substituted into 2.3 would lead to a gluino lifetime

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\*We have recently become aware of a previous treatment [11] of this decay mode.

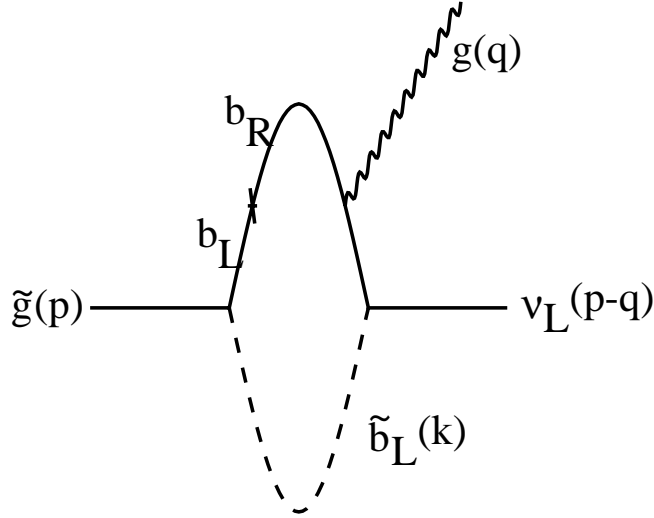


Figure 2: Gluino decay to gluon plus left-handed neutrino

depending only on the ratio of gluino mass to squark mass.

$$\tau(\tilde{g}) = .013s \left( \frac{\tilde{m}}{1000m_{\tilde{g}}} \right)^5 \left( \frac{0.1}{\alpha_s} \right) \left( \frac{7 \cdot 10^{-5}}{\lambda'_{i33}} \right)^2 \quad (2.6)$$

A gluino-gluon bound state with a lifetime of order .013s might have evaded the current searches since it would appear as a quasi-stable particle whose ultimate decay with a missing neutrino could be confused with a neutron knock-on event.

### 3 The gluino decay to gluon plus neutrino

If the gluino mass is less than twice the mass of the quarks appearing in the  $R$  parity violating couplings, one has the hitherto uninvestigated decay

$$\tilde{g} \rightarrow g\nu. \quad (3.1)$$

A recent analyses of constraints from Z decay suggests at 95% confidence level [14, 15]

$$m_{\tilde{g}} > 6.3 GeV/c^2. \quad (3.2)$$

This limit still allows the possibility that the gluino mass is below the b quark pair threshold. The matrix element corresponding to the graph of fig. 2 plus the analogous graph where the gluon is emitted from the squark line is

$$\mathcal{M} = \epsilon_\mu \frac{\lambda' g_3^2 m_b}{4} \bar{u}(p') \int \frac{d^4 k}{(2\pi)^4} \left( \frac{(\not{p}' + \not{k})\gamma^\mu + \gamma^\mu(\not{p} + \not{k})}{(p+k)^2 - m_b^2} + \frac{(2k-q)^\mu}{(k-q)^2 - \tilde{m}^2} \right) \cdot (1 - \gamma_5) u(p) \frac{1}{(p'+k)^2 - m_b^2} \frac{1}{k^2 - \tilde{m}^2} \quad (3.3)$$

where  $p' = p - q$  is the final state neutrino momentum.

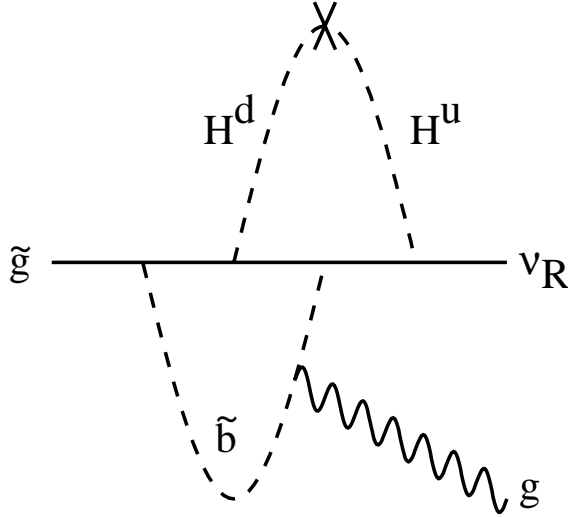


Figure 3: Typical Feynman graph for gluino decay to gluon plus right-handed neutrino

This amplitude is equivalent to that induced by an effective magnetic moment coupling

$$\mathcal{L} = i\mu_a \bar{u}_L(\nu) \sigma^{\mu\nu} q_\nu u(\tilde{g}) \epsilon_\mu(g) \quad (3.4)$$

with

$$\mu_a \approx \frac{m_b \alpha_s \lambda'}{\tilde{m}^2} \quad (3.5)$$

The corresponding decay rate is

$$\Gamma(\tilde{g} \rightarrow g\nu) = |\mu_a|^2 m_{\tilde{g}}^3 \approx \frac{m_b^2 m_{\tilde{g}}^3 \alpha_s^2 \lambda'^2}{\tilde{m}^4} \quad (3.6)$$

Nominal values of  $10\text{GeV}$ ,  $10\text{TeV}$ ,  $0.1$ , and  $7 \cdot 10^{-5}$  for  $m_{\tilde{g}}$ ,  $\tilde{m}$ ,  $\alpha_s$ , and  $\lambda'$ , would correspond to a gluino lifetime of  $5.2 \cdot 10^{-3}\text{s}$ .

A two loop graph that would lead to a gluino decay to gluon plus right-handed neutrino is shown in fig. 3. To investigate such two loop effects we consider an extended superpotential containing a right-handed singlet superfield  $N$ .

$$W = W_{MSSM} + \lambda' QDL + \epsilon H^u H^d N + h_\nu LNH^u \quad (3.7)$$

Here, lepton number and R parity violation comes through a new  $H^u H^d N$  interaction governed by the coupling constant  $\epsilon$  in addition to the conventional  $\lambda'$  coupling.  $W_{MSSM}$  contains the usual Higgs mixing term  $\mu H^u H^d$ . The small Yukawa coupling  $h_\nu$  is proportional to the neutrino Dirac mass:

$$h_\nu = \frac{m_\nu^{Dirac}}{\langle H^u \rangle} \quad (3.8)$$

The effective transition magnetic moment from fig. 3 is

$$\mu_a \approx \frac{1}{(4\pi)^3} \frac{\lambda' h_\nu h_b \alpha_s \mu B m_b}{\tilde{m}^2 m_H^2} \quad (3.9)$$

Here,  $\mu B$  is the off-diagonal entry in the Higgs mass squared matrix. In the MSSM with electroweak symmetry breaking [16], it is given by  $\mu B = \frac{1}{2} M_A^2 \sin(2\beta)$  where  $M_A$  is the mass of the CP-odd Higgs scalar.

This  $\mu_a$ , however, would be proportional to the neutrino mass and would be negligible compared to the transition magnetic moment of 3.5.

## 4 A dominant gluino decay to gluon plus right-handed neutrino

Even in the absence of the R parity violating quark-squark-lepton coupling of 2.1, the R parity and lepton number violating Higgs-Higgsino-Lepton coupling in 3.7 could lead to a gluino decay into gluon plus right-handed neutrino.

The lowest order graph contributing to gluino decay would be that of fig. 4 as well as those graphs related by attaching the gluon to other colored lines or by changing the flavor of the internal quark (squark) lines. These amplitudes are proportional to the trilinear boson coupling parameters  $A$ , which are induced in the softly broken MSSM thru supergravity. We can entertain the possibility that the  $\lambda'$  parameters are negligible and that the dominant

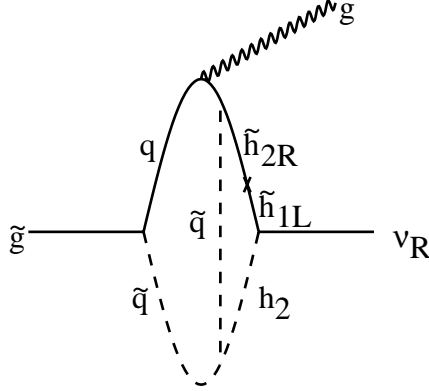


Figure 4: Alternative mechanism for gluino decay into gluon plus right handed neutrino

trilinear coupling is that of the top quark. Then the two loop gluino decays of fig. 4 could be dominant for a gluino LSP of mass up to the minimum of twice the top mass or twice the stop mass:

$$\mu_a \approx \frac{1}{(4\pi)^3} \frac{\mu \cos(2\beta) m_{\chi^0} A \epsilon \alpha_s h_t}{\tilde{m}^2 m_H^2} \quad (4.1)$$

where  $m_{\chi^0}$  is the mass of the neutralino. However, if the top quark is heavier than the neutralino, then  $m_{\chi^0}$  should be replaced by  $m_t$  in the estimate here.

Depending on the flavor structure, the  $\epsilon$  coupling might be limited only by neutrino mass measurements and might, therefore, be expected to be extremely small. It is clear that the corresponding gluino lifetime could easily be long enough to have cosmological significance. There is, for instance, the possibility that the gluino-gluon bound state could traverse cosmological distance scales before decaying and, if sufficiently energetic, could contribute through its decay products to the ultra-high-energy cosmic rays. We leave delayed calculation of some of the possible effects discussed here to future investigations.

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that gluino decays through bilinear R parity violation (as opposed to the trilinear violation treated here) have also been recently considered [17].



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